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(54) Abstract Title  
Voltage controlled oscillators

(57) Frequency modulation of a VCO's output is achieved by a modulating voltage (VM) fed to the oscillator's control line through an attenuator (28). In a preliminary measurement, the loop sensitivity of the VCO is measured at a number of frequency values (F1, F3, F5...Fn) distributed over the VCO's characteristic. This is done by setting the VCO to operate at each frequency (F1, F3, F5...Fn) in turn, and measuring the amount of control line voltage change which corresponds to a measured small change in the VCO output frequency at that frequency (F1, F3, F5...Fn). For each of these loop sensitivity values, the deviation sensitivity D of the VCO to a change in the modulating voltage (VM) is calculated. Finally, the attenuator settings (A1, A3, A5...An) necessary to provide a target VCO frequency modulation at each frequency (F1, F3, F5...Fn) can be calculated using the calculated deviation sensitivities (D1, D3, D5...Dn) and knowledge of the maximum value of the modulating signal (MS). From these calculated attenuator settings (A1, A3, A5...An), the attenuator setting  $A_F$  at any operating frequency F can be estimated, for example by interpolation. The oscillator may be used in a mobile radio or telephone.

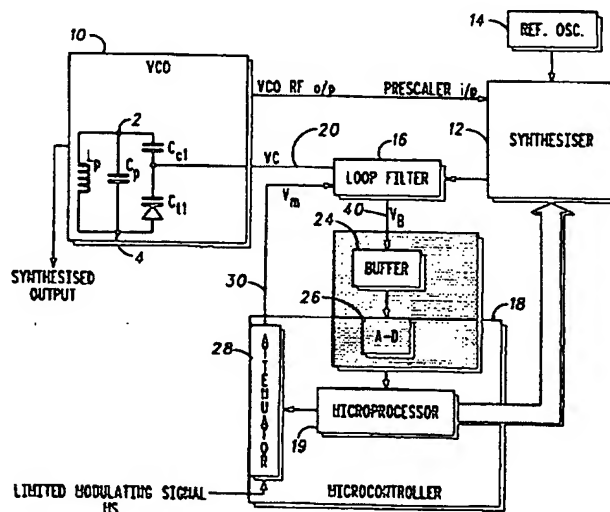
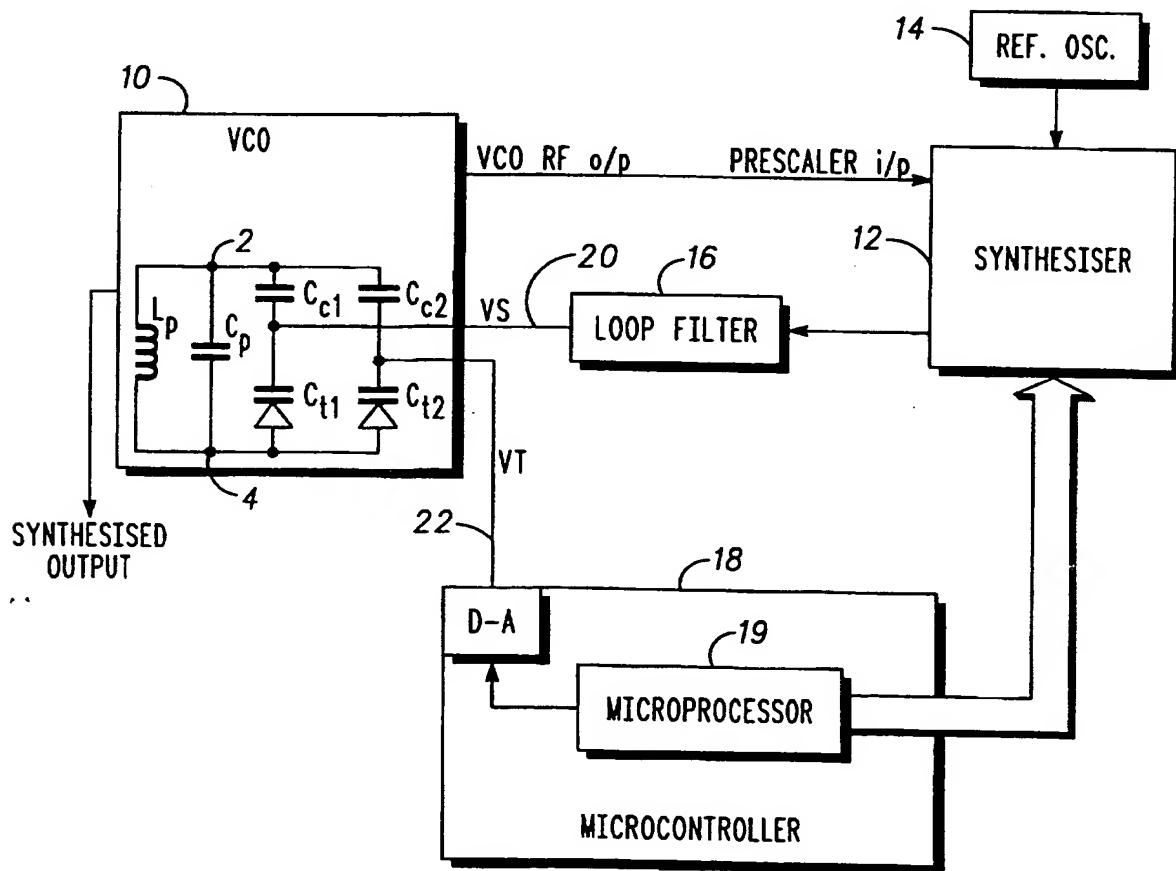
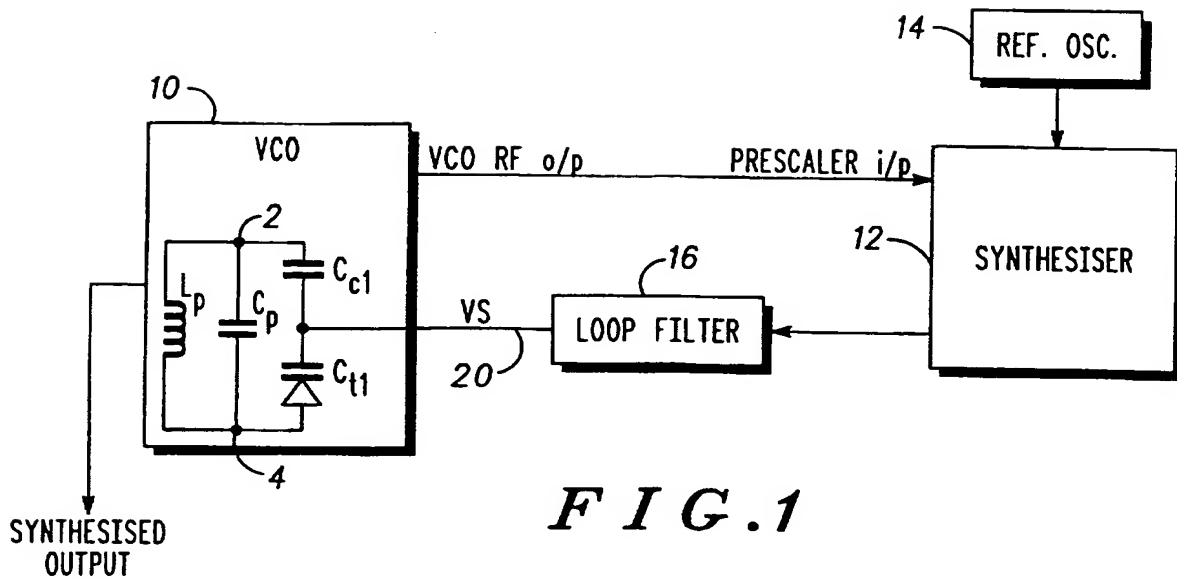
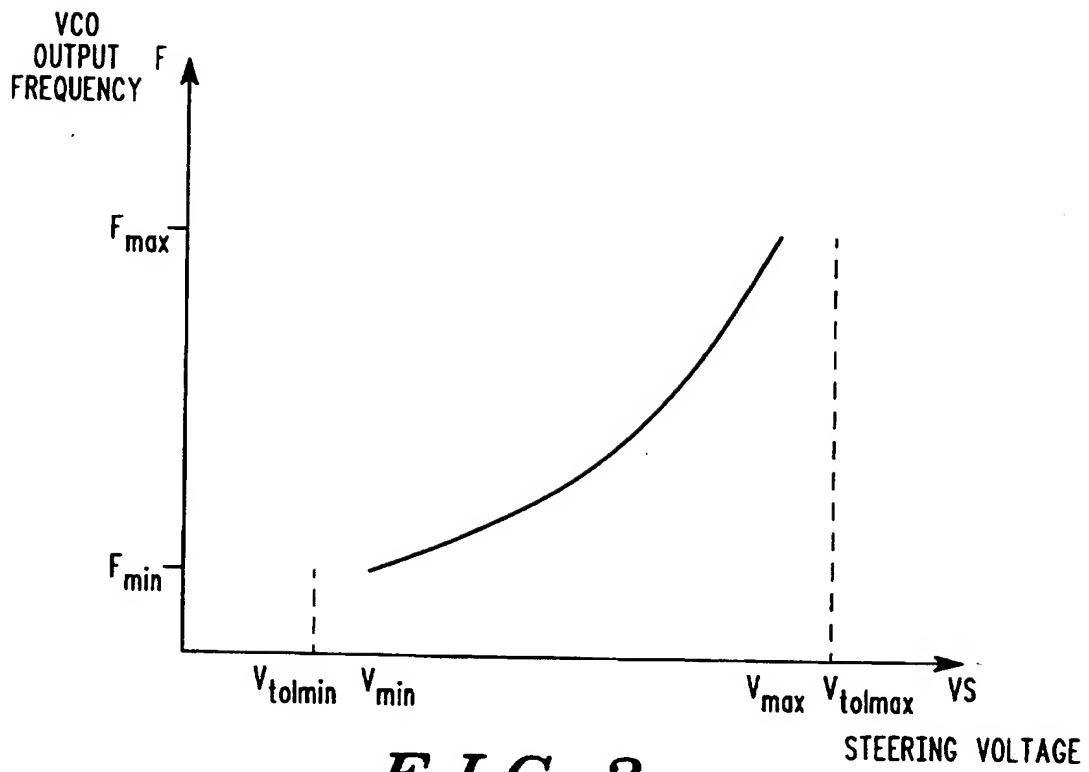


FIG. 4

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.



**FIG.3**

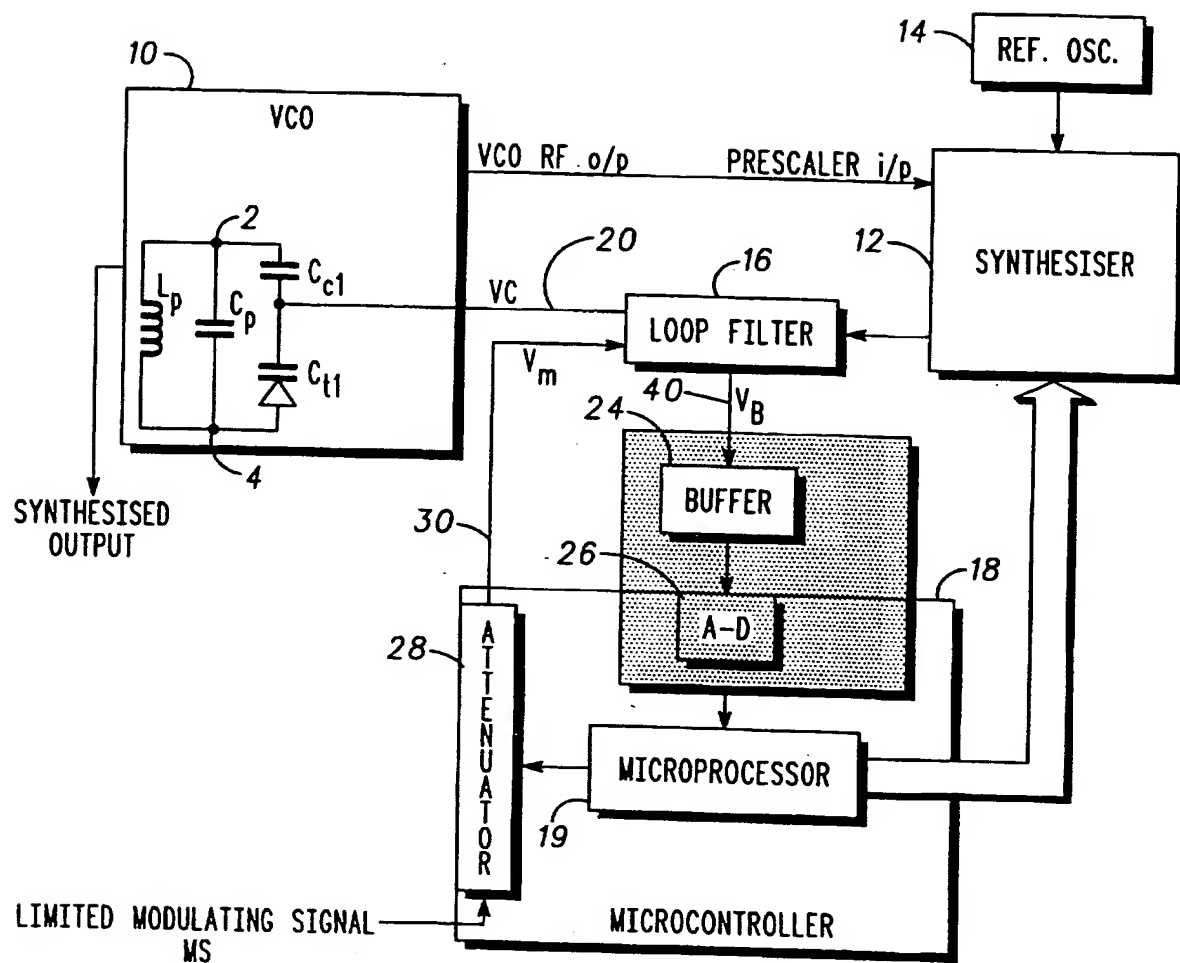


FIG. 4

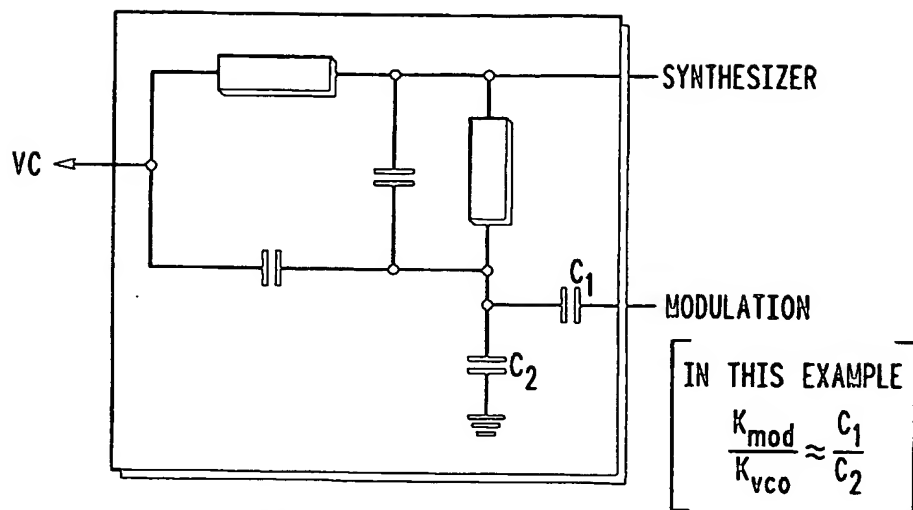


FIG. 5

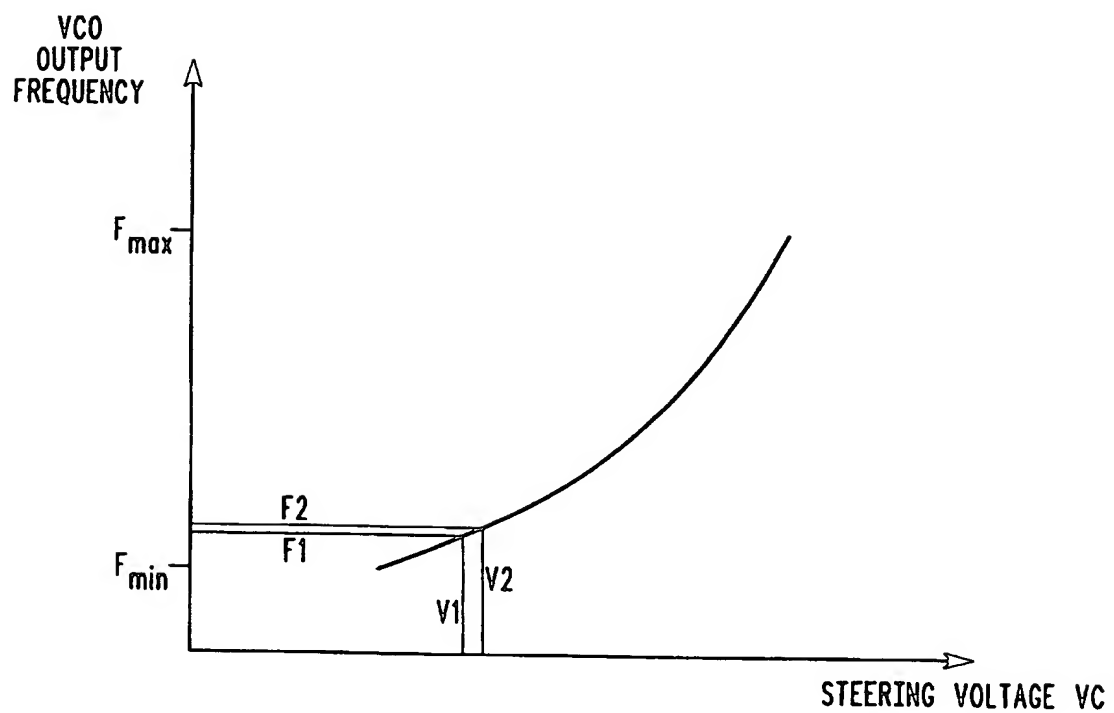


FIG. 6

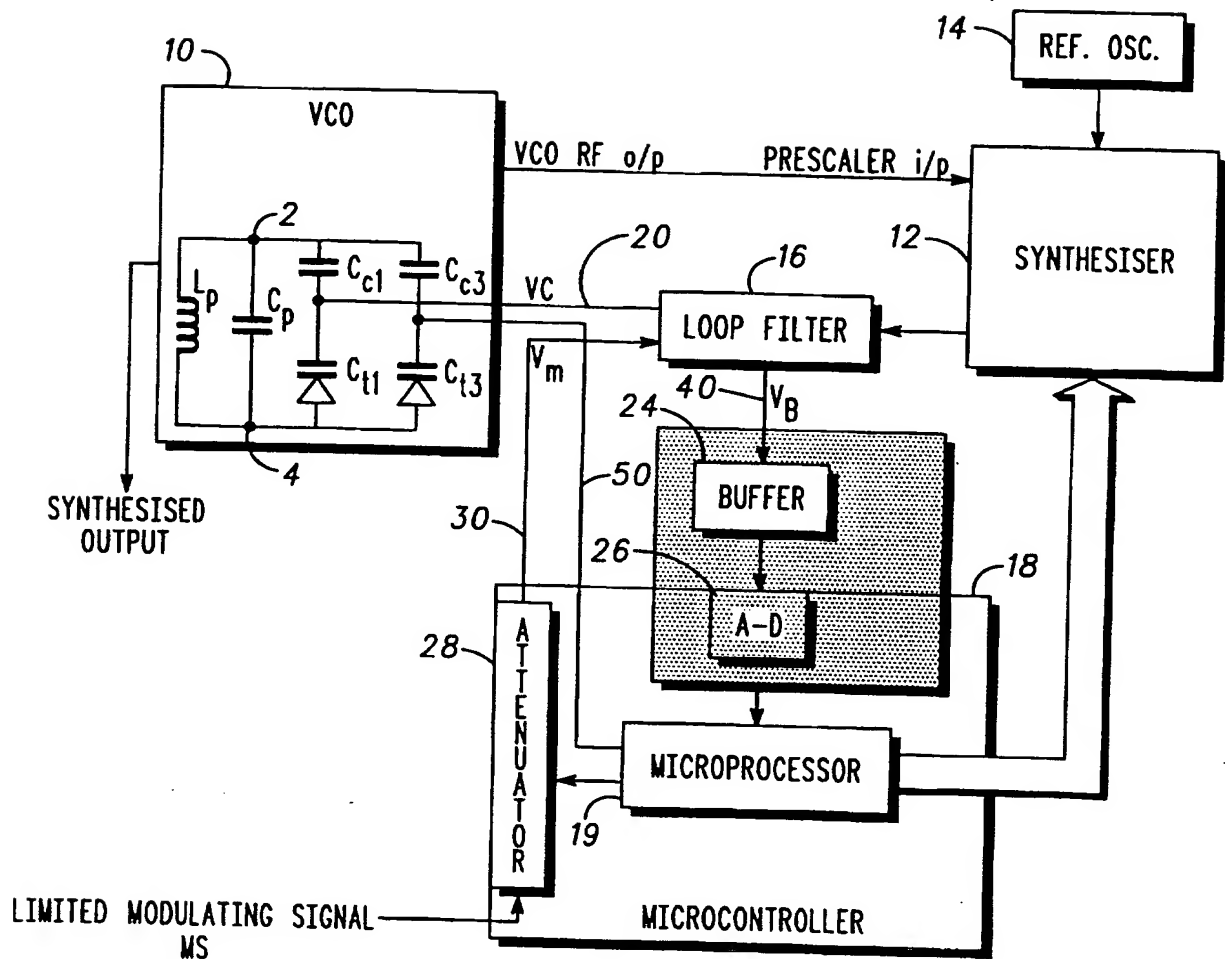


FIG. 7

Voltage Controlled OscillatorTechnical Field

5 The invention concerns a voltage controlled oscillator.

Background

10 A voltage controlled oscillator (VCO) is a circuit which is designed to produce an output signal of a particular frequency. This frequency is determined by the level of a voltage which is input to the oscillator. The output frequency of the oscillator can be varied by varying the magnitude of the voltage which is input to the oscillator. Typically, a voltage controlled oscillator may be used to provide a signal for transmission by the transmitter of a communications  
15 system.

20 The output frequency of the VCO can be varied reliably between a certain maximum frequency and a certain minimum frequency. The frequencies between these limits are referred to as the VCO's frequency range. There are however particular requirements for transmitter modulation linearity over a VCO's frequency range. Prior art designs of VCO often meet these requirements for transmitter modulation linearity only with great difficulty and expense.

25 A typical VCO design includes a parallel circuit comprising an inductor and a capacitor in the oscillator. Such a design is illustrated in figure 1, which includes an inductor  $L_p$  and a capacitor  $C_p$ . The frequency of the oscillations produced by the oscillator, for the moment disregarding the other components shown in figure 1, would simply be the resonant frequency of this parallel  
30 circuit. The parallel circuit comprising inductor  $L_p$  and  $C_p$  is shown in figure 1 to lie between a pair of terminals which are labelled 2 and 4 respectively.

Also connected to terminals 2 and 4 is a series circuit comprising a first varactor  $C_{t1}$  and a coupling capacitor  $C_{c1}$ . Varactor  $C_{t1}$  functions as a  
35 tuning capacitor, which can be tuned to a desired capacitance value by

applying a tuning voltage VS via the lead which bears reference 20. The tuning voltage is otherwise termed the 'steering' voltage. Although Ct1 is a varactor, a VCO can actually be constructed using any tuneable capacitor.

- 5 The voltage VS determines the capacitance value of the varactor Ct1. This capacitance value changes the total capacitance between terminals 2 and 4. This change in capacitance changes the resonant frequency of the circuitry connected between terminals 2 and 4, and thereby changes the frequency of the signal output by the VCO. The components illustrated in figure 1 therefore  
 10 provide an oscillator whose output frequency can be varied by varying the voltage on line 20. This is one basic design of VCO.

The arrangement of figure 1 shows a radio-frequency output from the oscillator 10, which is fed to a synthesiser 12. A further input to the  
 15 synthesiser 12 is provided by a reference oscillator 14. The output of the synthesiser 12 is fed to a loop filter 16, which provides the control voltage VS.

A further development of this basic VCO design is shown in figure 2. Figure 2 shows the main elements of one of the applicant's prior art VCO circuits.

20 Figure 2 comprises similar elements to those shown in figure 1. Additionally, figure 2 comprises a further varactor Ct2. A lead VT supplies a voltage to the varactor Ct2. The voltage on line VT provides compensation for the manufacturing tolerances of the components Lp, Cp and Ct1. Capacitor Cc2  
 25 is a coupling capacitor which connects varactor Ct2 to terminal 2, thus connecting it in parallel with the basic components Lp, Cp and Ct1 of the VCO.

Components Lp, Cp and Ct1 can only be manufactured with their values and  
 30 characteristics within certain margins of the intended, optimal values. These margins are the manufacturing tolerances.

In a theoretical circuit, a voltage of, for example, Vnominal volts would need to be supplied on line 20 in order to cause the VCO to produce a given output



signal with a frequency of  $F_{\text{nominal}}$ . However, in a practical circuit there are manufacturing tolerances which result in the actual voltage required on line 20 to produce the output signal of frequency  $F_{\text{nominal}}$  probably being slightly above or below the theoretical value  $V_{\text{nominal}}$ .

5 / The arrangement of figure 2 allows a compensation voltage  $V_T$  to be fed to varactor  $C_{t2}$  on line 22 in order to compensate for these manufacturing tolerances. This voltage  $V_T$  controls the capacitance value of varactor  $C_{t2}$ , and can therefore introduce an offset capacitance between the terminals 2  
10 and 4. The effect of this compensation is to change the frequency which is output by the VCO for a particular input voltage  $V_S$  on line 20. By choosing the correct value of  $V_T$ , the VCO can be made to produce the particular output frequency  $F_{\text{nominal}}$  in response to a voltage being input on line 20 which is very close to the theoretical voltage  $V_{\text{nominal}}$ . Thus compensation  
15 for manufacturing tolerances can largely be achieved. /

The arrangement of figure 2 includes circuitry to derive the signal  $V_T$ . This circuitry may include a microcontroller 18, having a microprocessor 19 and a digital-analogue converter to derive the actual voltage level  $V_T$  for line 22.

20 In the applicant's prior art design according to figure 2, line 22 could be supplied with any of eight different values of compensation voltage. Each value of this voltage provided optimum compensation for manufacturing tolerances when the VCO was operating in a different part of its operating  
25 frequency range.

The operating characteristic of a VCO takes the general form recognisable from figure 3. Figure 3 shows a typical graph of the output frequency of a VCO plotted against the steering voltage  $V_S$ . As figure 3 shows, the characteristic  
30 of the VCO is a curve, rather than a straight line.

The operating frequency range of the VCO of figure 2 has been shown on figure 3 as the portion of the curve between the frequency points marked as  $F_{\text{min}}$

and  $F_{\max}$ . These frequency points correspond to the voltage  $V_S$  taking the values  $V_{\min}$  and  $V_{\max}$  respectively.

Figure 3 also shows two dotted lines at voltage values  $V_{\text{tolmin}}$  and  $V_{\text{tolmax}}$ . These indicate respectively the minimum and maximum voltages  $V_S$  which might need to be supplied to real circuits of the design shown in figure 1 to provide output frequencies from  $F_{\min}$  to  $F_{\max}$ . These dotted lines highlight the superior accuracy of the compensated arrangement of figure 2 in comparison to the 'un-compensated' arrangement of figure 1.

10

Although the arrangement of figure 2 provides compensation for manufacturing tolerances, it has the added complexity of a second varactor and coupling capacitor.

15 In both the arrangements of figure 1 and figure 2, a modulating voltage may be applied to the varactor  $C_{t1}$ . This provides a frequency modulation on the output of the VCO. However, the characteristic of the VCO is a curve, as shown in figure 3. This means that a given magnitude of modulating voltage applied to the varactor will produce a frequency modulation whose magnitude  
20 depends on the position on the curve. This makes it very difficult to provide the desired amount of frequency modulation in the VCO's output signal.

In a circuit of the type shown in figure 1 or figure 2, typically, the level of modulating signal applied to the varactor diode  $C_{t1}$  must be varied across the  
25 operating range of the VCO to compensate for the non-uniform deviation sensitivity. An attenuator in the modulation voltage supply line may be used to do this. The modulation signal level that must be applied to a particular varactor to give the required deviation (output frequency modulation) is in fact found in accordance with the prior art by measuring the frequency modulation  
30 achieved on the VCO's output signal and adjusting the attenuator accordingly. This is repeated for several segments of the characteristic over which the deviation must be kept at a desired level. Each of these segments can be considered to be a 'tuning bin'. The modulation voltage may also be referred to as the 'audio' level.

Adding the modulating signal to the main control loop voltage is only one way of providing modulation to a VCO. However, such an arrangement is rare because of VCO non-linearity, both across and within the tuning bins.

5

Current techniques of providing modulation can employ a variable attenuator in the line supplying the modulation voltage. This method involves the following steps:

- (i) synthesise a frequency in the first tuning bin, typically at the centre; then
- 10 (ii) adjust an electronic attenuator until the desired magnitude of frequency modulation of the output signal measured on a test meter is obtained; then
- (iii) store this value in the radio for future use;
- (iv) repeat the process for each tuning bin.

- 15 Step (ii) involves adjusting the attenuator until a target amount of frequency modulation is obtained. This is under the condition of a known, modulating signal being input to the attenuator whilst the VCO is tuned to the particular frequency bin concerned. The step leads to an empirical setting for the attenuator, this being the setting which is required to
- 20 provide a pre-determined output frequency deviation.

The method described above is very time consuming. It also requires expensive test equipment in the factory.

25

### Summary of the Invention

- The invention provides a method of controlling the magnitude of the frequency modulation on the output signal of a voltage controlled oscillator at an operating frequency  $F$ , the magnitude of the frequency modulation depending
- 30 on the magnitude of a modulation voltage supplied to the control loop of the voltage controlled oscillator, the magnitude of the modulation voltage depending on both the magnitude of a modulating signal supplied to the voltage controlled oscillator and the variable attenuation setting  $A_f$  provided by an

attenuator, the modulating signal being supplied through the attenuator to provide the modulation voltage, the method comprising the steps of:

- (a) setting the voltage controlled oscillator to operate at a first operating frequency;
- 5 (b) measuring a first value of a control voltage, the control voltage being the voltage on the voltage control line of the voltage controlled oscillator, the first value of the control voltage being the value necessary to provide operation at the first operating frequency;
- (c) setting the voltage controlled oscillator to operate at a second operating
- 10 frequency, the second operating frequency differing by only a small frequency increment from the first operating frequency;
- (d) measuring a second value of the control voltage necessary to provide operation at the second operating frequency;
- (e) calculating the loop sensitivity of the voltage controlled oscillator to
- 15 changes of the control voltage at the first operating frequency as  $K_v$ , the ratio of the difference between the measured frequencies to the difference between the measured voltages;
- (f) calculating a first value of the deviation sensitivity of the voltage controlled oscillator at the first operating frequency as
- 20  $D_1 = K_0 \times K_v$   
 where  $K_0$  is a constant for the voltage controlled oscillator, the value of  $K_0$  depending on the amount of coupling of a change in the modulating voltage onto the voltage control line;
- (g) for the first value of the deviation sensitivity and for a particular maximum
- 25 level of the modulating signal, calculating a first attenuation setting for the variable attenuator, at the first frequency, the first attenuation setting being the setting of the attenuator which provides a target amount of frequency modulation on the output of the voltage controlled oscillator;
- (h) repeating steps (a) to (g) for a variety of operating frequencies distributed
- 30 over the operating frequency range of the voltage controlled oscillator, to derive values of the attenuation setting at these operating frequencies;
- (i) estimating the attenuation setting  $A_F$  for an operating frequency  $F$  from the values of the attenuation setting derived in steps (a)-(h), and, in operation at output frequency  $F$ , setting the attenuator to the attenuation setting  $A_F$  to

provide the target amount of frequency modulation on the output signal of the voltage controlled oscillator. /

5 A voltage controlled oscillator arrangement in accordance with the invention comprises:

a resonant circuit and a tuneable capacitor;  
 a synthesiser, loop filter and voltage control line, whereby in operation of the voltage controlled oscillator arrangement, the synthesiser and loop filter generate a control voltage on the voltage control line, and the control voltage  
 10 on the voltage control line is fed to the tuneable capacitor;  
 a microcontroller, comprising a microprocessor and measurement circuitry for measuring a voltage representative of the voltage on the voltage control line;  
 a variable attenuator for supplying a modulating voltage via a line, through the loop filter, to the voltage control line, the variable attenuator being  
 15 connected to the microcontroller;  
 whereby in operation of the voltage controlled oscillator arrangement at an operating frequency  $F$ , the microprocessor sets the attenuation setting  $A_F$  of the variable attenuator, the microprocessor estimating the required attenuation setting  $A_F$  for an operating frequency  $F$  based on calculations of  
 20 the attenuation setting for calculated values of the loop sensitivity  $K_v$  of the voltage controlled oscillator, the calculated values of the loop sensitivity  $K_v$  being based on measurements at various frequencies over the operating frequency range of the voltage controlled oscillator arrangement.

25 The present invention also encompasses a method of estimating the deviation sensitivity  $D_F$  of a voltage controlled oscillator at an operating frequency  $F$ , modulation of the output signal of the voltage controlled oscillator being provided by a modulation voltage, the method comprising the steps of:  
 (a) setting the voltage controlled oscillator to operate at a first operating  
 30 frequency;  
 (b) measuring a first value of a control voltage, the control voltage being the voltage on the voltage control line of the voltage controlled oscillator, the first value of the control voltage being the value necessary to provide operation at the first operating frequency;

- (c) setting the voltage controlled oscillator to operate at a second operating frequency, the second operating frequency differing by only a small frequency increment from the first operating frequency;
- (d) measuring a second value of the control voltage necessary to provide  
5 operation at the second operating frequency;
- (e) calculating the loop sensitivity of the voltage controlled oscillator to changes of the control voltage at the first operating frequency as  $K_v$ , the ratio of the difference between the measured frequencies to the difference between the measured voltages;
- 10 (f) calculating a first value of the deviation sensitivity of the voltage controlled oscillator at the first operating frequency as
- $$D_1 = K_0 \times K_v$$
- where  $K_0$  is a constant for the voltage controlled oscillator, the value of  $K_0$  depending on the amount of coupling of a change in the modulating voltage  
15 onto the voltage control line;
- (g) repeating steps (a) to (f) for a variety of operating frequencies distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the deviation sensitivity at these operating frequencies;
- (h) estimating the deviation sensitivity  $D_f$  of the voltage controlled oscillator  
20 for an operating frequency  $F$  from the values of the deviation sensitivity derived in steps (a)-(g).

Steps and features of further preferred embodiments of the invention are recited in the dependent claims.

25

#### Brief description of the drawings

Figure 1 shows a schematic view of a basic voltage controlled oscillator (VCO) circuit of the prior art.

30

Figure 2 shows a schematic view of a further VCO circuit of the prior art.

Figure 3 shows a graph of VCO output frequency plotted against the steering voltage  $V_S$ .

Figure 4 shows a voltage controlled oscillator in accordance with the invention.

Figure 5 shows an example of a loop filter suitable for use in the arrangement  
5 of figure 4.

Figure 6 illustrates a measurement step performed at a particular VCO  
operating frequency in the method of the invention.

10 Figure 7 shows a further voltage controlled oscillator in accordance with the  
invention.

#### Detailed description of the preferred embodiment

15 Figure 4 shows an arrangement in accordance with the present invention.  
Elements of figure 4 which have been described in connection with figures 1  
and 2 will not be described again here.

20 The arrangement of figure 4 contains a microprocessor 19 which forms part of  
a microcontroller 18, analogously to the arrangement of figure 2. However, the  
arrangement of figure 4 also includes an attenuator 28 under the control of  
microprocessor 19. The output of attenuator 28 is fed by line 30 to the loop  
filter 16.

25 The modulating signal MS which provides frequency modulation on the output  
of the VCO is fed to the input of the attenuator 28. This input signal to the  
attenuator can be assumed to be of limited maximum magnitude. The output  
from the attenuator 28 is a voltage signal VM. Signal VM is fed to the loop  
filter 16. The output of loop filter 16 is a voltage VC. Voltage VC is the tuning  
30 signal which is fed on voltage control line 20 to the varactor Ct1.

A VCO in accordance with the invention comprises a varactor Ct1 to which  
both the traditional 'steering line' voltage from synthesiser 12 and a voltage

derived from the modulating voltage VM are fed as a combined signal. In the arrangement of figure 4, this combined signal is voltage VC on line 20.

5 The output signals from the synthesiser 12 and the attenuator 28 are combined in the loop filter 16 to provide the voltage VC. Figure 5 shows an example of a loop filter which can combine these signals. The output of the attenuator 28 is supplied to capacitor C1 in the loop filter. On being input to the loop filter, the modulating voltage VM fed from attenuator 28 is reduced in magnitude in the ratio  $C1/(C1+C2)$  by the arrangement of capacitors C1 and  
10 C2. The output of the synthesiser 12 is fed to the loop filter 16 on the line shown at the top right of the filter.

Besides voltage control line 20, loop filter 16 has a further output line 40, shown on figure 4. Loop filter 16 outputs a voltage signal VB on line 40. The  
15 voltage signal VB is representative of the voltage VC on line 20. Voltage VB is fed to a buffer circuit 24. The output of buffer circuit 24 is measured by an A/D converter 26 and is fed to the microprocessor 19.

The invention involves determining the sensitivity of the VCO at different  
20 points on its frequency/voltage curve. Knowing this enables calculation of the optimum attenuator setting  $A_F$  at any VCO operating frequency F. The optimum attenuator setting  $A_F$  is the setting which results in the optimum modulating voltage VM being supplied to loop filter 16 in order to provide the desired amount of frequency modulation on the VCO's output. The sensitivity  
25 of the VCO is dependent on the sensitivity of the varactor Ct1, this being the amount of change in the varactor's capacitance per unit change in the voltage supplied to it.

Calculation of the optimum attenuator setting  $A_F$  at all VCO operating  
30 frequencies F requires knowledge of the sensitivity of the VCO at all steering voltages. The calculation itself requires both empirical steps and calculation. The empirical part of this method involves measuring the sensitivity of the VCO at a number of operating frequencies spaced along the VCO's operating frequency range. Then in normal operation of the VCO, an algorithm can be



used to calculate the optimum attenuator setting  $A_F$  at the point on the VCO's characteristic where it is currently operating.

5 A special test system command could initiate the measurement of the VCO's sensitivity. This could be done very rapidly in the factory. Alternatively, the radio could perform this measurement cycle every time that it is powered up. This measurement can also be performed at other times, for example when the radio loses lock. This is particularly advantageous for simple VCOs which are inherently non-linear. It is also particularly advantageous for radio designs  
10 which use many frequency segments to cover the desired operating frequency range, i.e. many 'tuning bins'.

In accordance with the invention., the initial measurement of the sensitivity of the VCO at a particular frequency is determined by the following steps (a)-(c),  
15 which should be read in conjunction with figure 6. For the purposes of this measurement, no modulating signal need be applied, i.e.  $V_M = 0$ .

(a) Firstly, the VCO is set to operate at a particular frequency  $F_1$ . The value of voltage  $V_C$  necessary to provide operation at this frequency  $F_1$  is  
20 measured. Assume that this measurement step yields a value for  $V_C$  of  $V_1$  at frequency  $F_1$ .

(b) Now the VCO's operating point, i.e. operating frequency, is moved a small amount. This is done by moving the steering line voltage a small amount,  
25 which in turn is achieved by varying the desired synthesised frequency from synthesiser 12 by a small amount. Assume that after this change the VCO is now operating at frequency  $F_2$ , and that the measured value of  $V_C$  is now  $V_2$ .

(c) The sensitivity of the varactor to changes of the voltage  $V_C$  can now be  
30 calculated. This is the loop sensitivity  $K_v$ . This is equal to:

$$K_v = (F_2 - F_1) / (V_2 - V_1)$$

The value of  $K_v$  is a measure of the amount of change in the output frequency  $F$  of the oscillator provided by a given change in the voltage  $VC$  on line 20. To a close approximation, this is the slope of the operating characteristic of the VCO in figure 6.

5

However, in operation the circuit of figure 4 supplies its modulating signal via attenuator 28 and loop filter 16 to the line 20.

The effect of a change in the voltage  $VM$  output by the attenuator 28 on voltage  $VC$  depends on the amount of coupling of the voltage through loop filter 16. This coupling can be treated as a constant  $K_0$ . In practice,  $K_0$  may depend simply on the ratio of the values of two components in the path through the loop filter connecting leads 30 and 20. These might be two resistors or two capacitors. In the loop filter illustrated in figure 5, these are the capacitors  $C1$  and  $C2$ .

15

Knowing  $K_v$ , the sensitivity of the VCO to changes in the voltage  $VM$  at frequency  $F$  can now be calculated. This is the deviation sensitivity  $D$ . The value of  $D$  at frequency  $F$  is

20

$$D = K_0 \times K_v$$

Using the value of  $K_v$  calculated at frequency  $F1$ , this equation yields a value  $D1$  for the deviation sensitivity at VCO operating frequency  $F1$ .

25

The modulation voltage  $VM$  required to provide a desired frequency modulation on the VCO's output at frequency  $F1$  can now be calculated as follows:

$$\text{Required deviation voltage} = \text{Target frequency deviation} / D$$

30

$$= \text{Target frequency deviation} / (K_0 \times K_v)$$

The amplitude of the modulating signal input to attenuator 28 is constant for the particular radio. Therefore an attenuation setting  $A1$  for the attenuator at

frequency  $F_1$  can be calculated simply by knowing this amplitude and the required deviation voltage at frequency  $F_1$ . The above calculation can clearly lead therefore to an attenuation setting  $A$  of attenuator 28 at any frequency  $F$  for which the loop sensitivity has been determined.

5

Steps (a) to (c) are now repeated for each of a number of different VCO output frequencies such as  $F_3, F_5, \dots, F_n$ . These frequency values should be distributed over the operating frequency range of the VCO. The resulting values of  $K_v$  are then representative of the loop sensitivity over the whole operating range of the VCO, i.e. over an entire curve such as that shown in figure 6. Similarly  
10 therefore, the values of the attenuator setting  $A_3, A_5 \dots A_n$  calculated for these frequencies are representative of the whole operating range of the VCO.

The initial measurement steps outlined above provide information about the  
15 characteristics of the characteristic curve shown in figure 6. Specifically, the loop sensitivities at measurement frequencies  $F_1, F_3, F_5 \dots F_n$  have been measured and the corresponding attenuator settings  $A_1, A_3, A_5 \dots A_n$  calculated.

20 In normal operation of the VCO, the attenuator should be set to the optimum value  $A_f$  at any operating frequency of the VCO, not just at the points such as  $F_1, F_3, F_5, \dots, F_n$  which were measured in the initial measurement steps. The arrangement of the invention can do this in various different ways.

25 In a preferred embodiment of the invention, the arrangement calculates the attenuator setting needed for any chosen VCO operating frequency. The attenuator setting  $A_f$  is calculated from measurements at two nearby frequencies where the sensitivity has been measured, one frequency lying above  $A_f$  and the other below. An algorithm interpolates between the two  
30 known attenuation settings  $A_1, A_3, A_5 \dots A_n$ , at the two nearby frequencies. This technique can be used at all operating frequencies in the VCO's operating range to derive the value of the attenuator setting  $A_f$  which provides the desired amount of frequency modulation at frequency  $F$ .

This embodiment can be understood in detail by considering the following short algorithm of steps (i)- (iii) below. This algorithm assumes that the radio has measured the VCO sensitivity at the top and bottom frequency values of a number of frequency bins. A detailed algorithm for doing this preliminary measurement is shown in appendix 1 at the end of this description. The radio would employ an algorithm consisting of the following steps to determine the attenuator value to use at any frequency  $F$ :

- (i) Starting from the chosen operating frequency  $F$  of the radio, work out which frequency bin this frequency lies in via a look up-table or 'bin-pointer';
- (ii) Work out where within this bin the VCO is operating, relative to the top and bottom limits of that frequency bin; and
- (iii) Interpolate between the upper and lower calculated attenuation values for the selected bin.

In an alternative embodiment of the invention, a curve fitting algorithm can be employed instead of the interpolation technique. In the curve fitting embodiment, a software algorithm calculates the 'best fit' curve to the values of attenuation settings  $A_1, A_2, A_3 \dots A_n$  which were measured for the VCO in the initial measurement step. The value of attenuation setting  $A_F$  required at any VCO operating frequency  $F$  can then be calculated simply from this curve.

It is notable that these two embodiments outlined above may not lead to the same attenuator setting  $A_F$  for a given VCO operating frequency  $F$ . However, the accuracy of the frequency modulation achievable by the attenuator 28 is in any case limited by the resolution of the attenuator. The attenuator might typically be able to take on one of 256 different settings under the control of microprocessor 19. This coarseness limits the precision to which the frequency modulation of the VCO can be set.

In operation, the microcontroller of the present invention can select the attenuator setting  $A_F$  calculated to best suit any operating frequency  $F$  within

its operating frequency range. When a radio incorporating this arrangement is tuned to a particular frequency, the microcontroller uses this frequency to either interpolate or calculate the optimum attenuator setting. This setting is then supplied to attenuator 28. This attenuator setting is then used until the

5 VCO is re-tuned to an operating frequency sufficiently different from the initial frequency that the microcontroller decides that a different attenuator setting is necessary to provide the desired amount of frequency modulation. This new attenuator setting is then used.

10 The arrangement offers several advantages. These include the following:

1. The VCO's variable modulation deviation sensitivity is compensated for automatically each time that the method of the invention is applied.
2. Tuning takes very little time. This is because the tuning is performed under
- 15 radio control with no remote control.
3. Because the deviation is adjusted optimally every time, the effect of component ageing tolerances is eliminated.
4. Because the VCO is adjusted optimally every time, the effect of component variations with temperature is eliminated.

20

The arrangement of figure 4 shows a single varactor Ct1. However, the invention can also be employed in an arrangement which comprises a further varactor. Such an arrangement is shown in figure 7.

- 25 The further varactor Ct3, and a coupling capacitor Cc3, can be connected between terminals 2 and 4, in a similar fashion to varactor Ct1 and coupling capacitor Cc1. The further varactor is then fed via a line 50 with one of a series of discrete voltages produced by the microcontroller 18. Each discrete voltage provides a discrete capacitance increment to the oscillator, thereby
- 30 determining in 'coarse' increments the point on the oscillator's characteristic at which the oscillator operates. Each discrete voltage fed to this further varactor Ct3 thus selects a different 'frequency bin' within which the VCO operates.

In this arrangement, the first varactor Ct1 is fed with voltages which vary over a comparatively narrow range. This narrow range is less than the whole operating frequency range of the VCO, and determines the exact operating frequency of the oscillator within the frequency bin which has been selected by the voltage fed to the further varactor Ct3.

Applying the invention to this arrangement, the empirical measurement of the loop sensitivity  $K_v$  and the Deviation sensitivity are performed at least once within each frequency bin set by varactor Ct3. Preferably, two such measurements are performed within each frequency bin, at frequencies around the top and bottom of the bin. In operation then, an estimate of the attenuator setting  $A_f$  can be made at any operating frequency  $F$  by interpolation between these measured values within the bin.

The VCO arrangement and the method of the invention may be used in a portable- or a mobile radio, or in a mobile telephone.

#### Appendix 1

The following algorithm is an example falling within the terms of the invention. This algorithm provides measured values of the VCO loop sensitivity and attenuator setting for frequencies at the top and bottom of each of a number of frequency bins. These bins span the VCO's operating frequency range.

1. Set synthesiser to desired lowest frequency  $F_{b1}$  in bin =  $F(1)$
2. Measure  $VC = VC_{low1}$
3. Set synthesiser to frequency  $F_{b2}$ , equal to frequency  $F(1)$  plus a small offset.
4. Measure  $VC = VC_{low2}$
5. Calculate loop sensitivity  $K_v = (F_{b2} - F_{b1}) / (VC_{low2} - VC_{low1})$
6. Calculate corresponding Deviation sensitivity =  $K_0 \times K_v$ , where  $K_0$  is the ratio of 2 resistors in the VCO.

7. Calculate required deviation voltage  

$$= \text{Target Frequency Deviation} / (K_o \times K_v)$$
8. Calculate required attenuator setting to give required deviation voltage.  
 The unattenuated modulating amplitude is known for a given radio design. The  
 5 tolerance errors are very small with modern components.
9. Store required attenuator setting for the bottom of this bin as Ab1.
10. Repeat steps 1-9 for a frequency at the top of the tuning bin, replacing  
 Fb1, Fb2, VClow1, VClow2 and Ab1 with respectively Ft1, Ft2, VCtop1,  
 VCtop2 and At1. At1 is the required attenuation for the top of the bin.
- 10 11. Repeat steps 1-10 for other frequency bins.
12. The radio now has accurate attenuator settings at selected frequencies  
 over its tuning range.

## Claims

1. A method of controlling the magnitude of the frequency modulation on the output signal of a voltage controlled oscillator at an operating frequency F, the  
 5 magnitude of the frequency modulation depending on the magnitude of a modulation voltage (VM) supplied to the control loop of the voltage controlled oscillator, the magnitude of the modulation voltage (VM) depending on both the magnitude of a modulating signal (MS) supplied to the voltage controlled oscillator and the variable attenuation setting  $A_F$  provided by an attenuator  
 10 (28), the modulating signal (MS) being supplied through the attenuator (28) to provide the modulation voltage (VM), the method comprising the steps of:

- (a) setting the voltage controlled oscillator to operate at a first operating frequency (F1);  
 15
- (b) measuring a first value (VC1) of a control voltage (VC), the control voltage (VC) being the voltage on the voltage control line (20) of the voltage controlled oscillator, the said first value (VC1) of the control voltage being the value necessary to provide operation at the said first operating frequency (F1);  
 20
- (c) setting the voltage controlled oscillator to operate at a second operating frequency (F2), the second operating frequency (F2) differing by only a small frequency increment from the first operating frequency (F1);
- 25 (d) measuring a second value (VC2) of the control voltage (VC) necessary to provide operation at the said second operating frequency (F2);
- (e) calculating the loop sensitivity ( $K_v$ ) of the voltage controlled oscillator at the said first operating frequency (F1) to changes of the control voltage (VC)  
 30 as

$$K_v = (F2-F1)/(V2-V1)$$



(f) calculating a first value of the deviation sensitivity (D1) of the voltage controlled oscillator at the said first operating frequency (F1) as

$$D1 = K_0 \times K_v$$

5

where  $K_0$  is a constant for the voltage controlled oscillator, the value of  $K_0$  depending on the amount of coupling of a change in the modulating voltage (VM) onto the voltage control line (20);

10 (g) for the said first value of the deviation sensitivity (D1) and for a particular maximum level of the modulating signal (MS), calculating a first attenuation setting (A1) for the said variable attenuator (28), at the said first frequency (F1), the first attenuation setting (A1) being the setting of the attenuator (28) which provides a target amount of frequency modulation on the output of the  
15 voltage controlled oscillator;

(h) repeating steps (a) to (g) for a variety of operating frequencies (F3, F5...Fn) distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the attenuation setting (A3, A5,...An) at these  
20 operating frequencies (F3, F5,...Fn);

(i) estimating the attenuation setting  $A_F$  for an operating frequency F from the values of the attenuation setting (A1, A3, A5,...An) derived in steps (a)-(h), and, in operation at output frequency F, setting the attenuator to the  
25 attenuation setting  $A_F$  to provide the said target amount of frequency modulation on the output signal of the voltage controlled oscillator.

2. A method in accordance with claim 1, wherein, in operation of the voltage controlled oscillator, the modulating signal (MS) is magnitude limited, and the  
30 particular maximum level used in the calculation of step (g) is the magnitude which the modulating signal (MS) cannot exceed.

3. A method in accordance with claim 1 or claim 2, whereby step (i) further comprises interpolating between the values of the attenuation setting (A1,

A3, A5,...An) derived for the next nearest frequencies (F1, F3, F5,...Fn) above and below frequency F, to estimate the attenuation value  $A_F$ .

4. A method in accordance with claim 1 or claim 2, whereby step (i) further  
5 comprises fitting a curve to the derived values of the attenuation setting (A1, A3, A5,...An) and estimating the value of attenuation setting  $A_F$  for the operating frequency F from the said curve.

5. A method in accordance with any of claims 1-4, wherein the value of  $K_o$   
10 depends on the values of two capacitors C1 and C2 in the path of the modulating voltage (VM) to the voltage control line (20).

6. A method in accordance with any of claims 1-5, wherein the attenuator (28)  
15 is controlled digitally, and is set to the nearest digital value to the estimated attenuation setting  $A_F$ .

7. A voltage controlled oscillator arrangement, comprising:

a resonant circuit (Lp, Cp) and a tuneable capacitor (Ct1);

20

a synthesiser (12), loop filter (16) and voltage control line (20), whereby in operation of the voltage controlled oscillator arrangement, the said synthesiser (12) and said loop filter (16) generate a control voltage (VC) on the said voltage control line (20), and the control voltage (VC) on the said voltage  
25 control line (20) is fed to the said tuneable capacitor (Ct1);

a microcontroller (18), comprising a microprocessor (19) and measurement circuitry (24, 26) for measuring a voltage (VB) representative of the voltage (VC) on the said voltage control line (20);

30

a variable attenuator (28) for supplying a modulating voltage (VM) via a line (30), through said loop filter (16), to the said voltage control line (20), the variable attenuator (28) being connected to said microcontroller (18);

whereby in operation of the voltage controlled oscillator arrangement at an operating frequency  $F$ , the microprocessor (19) sets the attenuation setting  $A_F$  of the said variable attenuator (28), the said microprocessor (19)

5 estimating the required attenuation setting  $A_F$  for an operating frequency  $F$  based on calculations of the attenuation setting ( $A_1, A_3, A_5, \dots A_n$ ) for calculated values of the loop sensitivity  $K_v$  of the voltage controlled oscillator, the calculated values of the loop sensitivity  $K_v$  being based on measurements at various frequencies ( $F_1, F_3, F_5, \dots F_n$ ) over the operating frequency range of

10 the voltage controlled oscillator arrangement.

8. A voltage controlled oscillator arrangement in accordance with claim 7, wherein the microprocessor (19) estimates the required attenuation setting  $A_F$  for an operating frequency  $F$  by interpolation between calculated values for

15 the attenuation setting ( $A_1, A_3, A_5, \dots A_n$ ) at the next nearest frequencies ( $F_1, F_3, F_5, \dots F_n$ ) above and below operating frequency  $F$ .

9. A voltage controlled oscillator arrangement in accordance with claim 7 or claim 8, wherein the said tuneable capacitor ( $C_{t1}$ ) is a varactor, and further

20 comprising a further varactor ( $C_{t3}$ ) connected in parallel to the said resonant circuit ( $L_p, C_p$ ), whereby in operation of the voltage controlled oscillator one of a set of discrete voltages is fed to the said further varactor ( $C_{t3}$ ) by the microcontroller (18) to provide a frequency bin within which the voltage controlled oscillator operates, the first said varactor ( $C_{t1}$ ) being fed with a

25 control voltage ( $V_C$ ) variable over a comparatively narrow range to determine the exact operating frequency  $F$  of the voltage controlled oscillator within the selected frequency bin.

10. A method of estimating the deviation sensitivity  $D_F$  of a voltage controlled

30 oscillator at an operating frequency  $F$ , modulation of the output signal of the voltage controlled oscillator being provided by a modulation voltage ( $V_M$ ), the method comprising the steps of:

- (a) setting the voltage controlled oscillator to operate at a first operating frequency (F1);
- 5 (b) measuring a first value (VC1) of a control voltage (VC), the control voltage (VC) being the voltage on the voltage control line (20) of the voltage controlled oscillator, the said first value (VC1) of the control voltage being the value necessary to provide operation at the said first operating frequency (F1);
- 10 (c) setting the voltage controlled oscillator to operate at a second operating frequency (F2), the second operating frequency (F2) differing by only a small frequency increment from the said first operating frequency (F1);
- (d) measuring a second value (VC2) of the control voltage (VC) necessary to provide operation at the said second operating frequency (F2);
- 15 (e) calculating the loop sensitivity ( $K_v$ ) of the voltage controlled oscillator at the said first operating frequency (F1) to changes of the control voltage (VC) as
- 20 
$$K_v = (F2 - F1) / (V2 - V1)$$
- (f) calculating a first value of the deviation sensitivity (D1) of the voltage controlled oscillator at the said first operating frequency (F1) as
- 25 
$$D1 = K_0 \times K_v$$
- where  $K_0$  is a constant for the voltage controlled oscillator, the value of  $K_0$  depending on the amount of coupling of a change in the modulating voltage (VM) onto the voltage control line;
- 30 (g) repeating steps (a) to (f) for a variety of operating frequencies (F3, F5...Fn) distributed over the operating frequency range of the voltage controlled oscillator, to derive values of the deviation sensitivity (D3, D5,...Dn) at these operating frequencies (F3, F5,...Fn);

(h) estimating the deviation sensitivity  $D_F$  of the voltage controlled oscillator for an operating frequency  $F$  from the values of the deviation sensitivity ( $D1$ ,  $D3$ ,  $D5$ ,... $D_n$ ) derived in steps (a)-(g).

5

11. A method in accordance with claim 10, whereby step (h) further comprises interpolating between the derived values of deviation sensitivity ( $D1$ ,  $D3$ ,  $D5$ ... $D_n$ ) at the next nearest frequencies ( $F1$ ,  $F3$ ,  $F5$ ... $F_n$ ) above and below frequency  $F$  to estimate the value of the deviation sensitivity  $D_F$  for operating frequency  $F$ .

10

12. A method in accordance with claim 10, whereby step (h) further comprises fitting a curve to the derived values of deviation sensitivity ( $D1$ ,  $D3$ ,  $D5$ ... $D_n$ ) and estimating the value of the deviation sensitivity  $D_F$  at operating frequency  $F$  from the said curve.

15

13. A method in accordance with any of claims 10-12, wherein the value of  $K_0$  depends on the values of two capacitors  $C1$  and  $C2$  in the path of the modulating voltage ( $VM$ ) to the voltage control line (20).

20

14. A voltage controlled oscillator arrangement substantially as hereinbefore described with reference to, or as illustrated by, any of figures 4,6 or 7 of the drawings.



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**Patents Act 1977**  
**Search Report under Section 17**

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H3A: AE; H3R: RFMA; G1U:UR2906

Int Cl (Ed.6): G01R, H03C, H03L

Other: Online: WPI, JAPIO, INSPEC

**Documents considered to be relevant:**

Category	Identity of document and relevant passage	Relevant to claims
A	US 4309674 OWEN - see especially figures 2,3 and columns 2-4	1, 7 and 10

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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